

Claims

What is claimed is:

1. A method for determining an electrical property of a formation, comprising:
 - acquiring a first resistivity measurement by energizing a first transmitter and receiving a first signal in a first receiver, wherein the first transmitter and the first receiver are disposed on the logging tool in a first orientation substantially parallel to a longitudinal axis of the logging tool;
 - acquiring a second resistivity measurement by energizing a second transmitter and receiving a second signal in a second receiver, wherein the second transmitter and the second receiver are disposed on the logging tool in a second orientation that is substantially orthogonal to the first orientation; and
 - deriving the electrical property of the formation from a difference measurement that is derived from the first resistivity measurement and the second resistivity measurement.
2. The method of claim 1, wherein the difference measurement is derived from $\alpha(\beta V_1 - V_2)$, wherein α and β are constants, V_1 is the first resistivity measurement, and V_2 is the second resistivity measurement.
3. The method of claim 2, wherein α is 1 and β is 1.
4. The method of claim 2, wherein α is 1/2 and β is 3/2.
5. The method of claim 1, wherein the formation is anisotropic and the method further comprising deriving an anisotropic resistivity ratio from the first resistivity measurement and the second resistivity measurement.

6. The method of claim 5, wherein the deriving the anisotropic resistivity ratio is based on $V_1/2V_2$, where V_1 is the first resistivity measurement and V_2 is the second resistivity measurement.
7. The method of claim 6, wherein the derived electrical property of the formation comprises a horizontal conductivity.
8. The method of claim 7, further comprising deriving a vertical conductivity from the horizontal conductivity and the anisotropic resistivity ratio.
9. The method of claim 8, further comprising obtaining a refined horizontal conductivity and a refined vertical conductivity by using the derived horizontal conductivity and the derive vertical conductivity in an iterative solver.
10. A method for estimating an anisotropic resistivity ratio of an anisotropic formation, comprising:
 - acquiring a first resistivity measurement by energizing a first transmitter and receiving a first signal in a first receiver, wherein the first transmitter and the first receiver are disposed on the logging tool in a first orientation substantially parallel to a longitudinal axis of the logging tool;
 - acquiring a second resistivity measurement by energizing a second transmitter and receiving a second signal in a second receiver, wherein the second transmitter and the second receiver are disposed on the logging tool in a second orientation that is substantially orthogonal to the first orientation;
 - and
 - deriving the anisotropic resistivity ratio from a ratio of the first resistivity measurement and the second resistivity measurement.
11. The method of claim 10, wherein the ratio is $V_1/2V_2$, where V_1 is the first resistivity measurement and V_2 is the second resistivity measurement.

12. A method for determining a dip angle in a formation having dipping planes, comprising:

acquiring tri-axial resistivity measurements using a tri-axial logging tool;
deriving an estimate of horizontal resistivity from a difference measurement between two orthogonal sets of measurements derived from the tri-axial measurements; and
determining the dip angle from the tri-axial resistivity measurements and the estimate of horizontal resistivity.

13. The method of claim 12, wherein the determining the dip angle is according to an equation selected from

$$\alpha = \tan^{-1} \frac{L_h - T'_{zz}}{T'_{xz}},$$

$$\alpha = 0.5 \tan^{-1} \frac{T'^2_{xz} + (L_h - T'_{zz})(T_h - T'_{xx})}{T_h - L_h + T'_{zz} - T'_{xx}},$$

$$\alpha = 0.5 \tan^{-1} \frac{2T'^2_{xz}}{(T'_{zz} - T'_{xx}) - (L_h - T_h)}, \text{ and}$$

$$\alpha = \tan^{-1} \sqrt{\frac{T'_{zz} - L_h}{T'_{xx} - T_h}},$$

wherein T'_{xx} , T'_{xz} , and T'_{zz} are strike-rotated xx, xz, and zz couplings, respectively, and L_h and T_h are zz and xx couplings, respectively, in an isotropic formation.

14. A method for determining an electrical property of a formation from tri-axial resistivity measurements acquired with a tri-axial logging tool, comprising:

obtaining from the tri-axial resistivity measurements a first set of measurements representing couplings between a longitudinal transmitter and a longitudinal receiver;

obtaining from the tri-axial resistivity measurements a second set of measurements representing couplings between a transverse transmitter and a transverse receiver; and

deriving the electrical property of the formation from a difference measurement that is derived from the first set of measurements and the second set of measurements.

15. The method of claim 14, wherein the difference measurement is derived from $\alpha(\beta V_1 - V_2)$, wherein α and β are constants, V_1 is the first set of measurements, and V_2 is the second set of measurements.
16. The method of claim 15, wherein α is 1 and β is 1.
17. The method of claim 15, wherein α is 1/2 and β is 3/2.
18. The method of claim 14, wherein the formation is anisotropic and the method further comprising deriving an anisotropic resistivity ratio from the first set of measurements and the second set of measurements.
19. The method of claim 18, wherein the deriving the anisotropic resistivity ratio is based on $V_1/2V_2$, where V_1 is the first set of measurements and V_2 is the second set of measurements.
20. The method of claim 19, wherein the derived electrical property of the formation comprises a horizontal conductivity.
21. The method of claim 20, further comprising deriving a vertical conductivity from the horizontal conductivity and the anisotropic resistivity ratio.
22. The method of claim 21, further comprising obtaining a refined horizontal conductivity and a refined vertical conductivity by using the derived horizontal conductivity and the derive vertical conductivity in an iterative solver.

23. A method for estimating an anisotropic resistivity ratio of an anisotropic formation from tri-axial resistivity measurements acquired with a tri-axial logging tool, comprising:
- obtaining from the tri-axial resistivity measurements a first set of measurements representing couplings between a longitudinal transmitter and a longitudinal receiver;
 - obtaining from the tri-axial resistivity measurements a second set of measurements representing couplings between a transverse transmitter and a transverse receiver; and
 - deriving the anisotropic resistivity ratio from a ratio of the first set of measurements and the second set of measurements.
24. The method of claim 23, wherein the ratio is $V_1/2V_2$, where V_1 is the first set of measurements and V_2 is the second set of measurements.
25. A method for determining a dip angle in a formation having dipping planes from tri-axial resistivity measurements acquired with a tri-axial logging tool, comprising:
- obtaining from the tri-axial resistivity measurements a first set of measurements representing couplings between a longitudinal transmitter and a longitudinal receiver;
 - obtaining from the tri-axial resistivity measurements a second set of measurements representing couplings between a transverse transmitter and a transverse receiver; and
 - deriving an estimate of horizontal resistivity from a difference measurement derived from the first set of measurements and the second set of measurements; and
 - determining the dip angle from the tri-axial resistivity measurements and the estimate of horizontal resistivity.

26. The method of claim 25, wherein the determining the dip angle is according to an equation selected from

$$\alpha = \tan^{-1} \frac{L_h - T'_{zz}}{T'_{xz}},$$

$$\alpha = 0.5 \tan^{-1} \frac{T'^2_{xz} + (L_h - T'_{zz})(T_h - T'_{xx})}{T_h - L_h + T'_{zz} - T'_{xx}},$$

$$\alpha = 0.5 \tan^{-1} \frac{2T'^2_{xz}}{(T'_{zz} - T'_{xx}) - (L_h - T_h)}, \text{ and}$$

$$\alpha = \tan^{-1} \sqrt{\frac{T'_{zz} - L_h}{T'_{xx} - T_h}},$$

wherein T'_{xx} , T'_{xz} , and T'_{zz} are strike-rotated xx, xz, and zz couplings, respectively, and L_h and T_h are zz and xx couplings, respectively, in an isotropic formation.

27. A system for determining an electrical property of a formation, comprising:

a computer having a memory storing a program having instructions for:

acquiring a first resistivity measurement by energizing a first transmitter and receiving a first signal in a first receiver, wherein the first transmitter and the first receiver are disposed on the logging tool in a first orientation substantially parallel to a longitudinal axis of the logging tool;

acquiring a second resistivity measurement by energizing a second transmitter and receiving a second signal in a second receiver, wherein the second transmitter and the second receiver are disposed on the logging tool in a second orientation that is substantially orthogonal to the first orientation; and

deriving the electrical property of the formation from a difference measurement that is derived from the first resistivity measurement and the second resistivity measurement.

28. The system of claim 27, wherein the difference measurement is derived from $\alpha(\beta V_1 - V_2)$, wherein α and β are constants, V_1 is the first resistivity measurement, and V_2 is the second resistivity measurement.
29. A system for estimating an anisotropic resistivity ratio of an anisotropic formation, comprising a computer having a memory storing a program having instructions for:
 - acquiring a first resistivity measurement by energizing a first transmitter and receiving a first signal in a first receiver, wherein the first transmitter and the first receiver are disposed on the logging tool in a first orientation substantially parallel to a longitudinal axis of the logging tool;
 - acquiring a second resistivity measurement by energizing a second transmitter and receiving a second signal in a second receiver, wherein the second transmitter and the second receiver are disposed on the logging tool in a second orientation that is substantially orthogonal to the first orientation;
 - and
 - deriving the anisotropic resistivity ratio from a ratio of the first resistivity measurement and the second resistivity measurement.
30. The system of claim 29, wherein the ratio is $V_1/2V_2$, where V_1 is the first resistivity measurement and V_2 is the second resistivity measurement.
31. A system for determining a dip angle in a formation having dipping planes, comprising a computer having a memory storing a program having instructions for:
 - acquiring tri-axial resistivity measurements using a tri-axial logging tool;

- deriving an estimate of horizontal resistivity from a difference measurement between two orthogonal sets of measurements derived from the tri-axial measurements; and
- determining the dip angle from the tri-axial resistivity measurements and the estimate of horizontal resistivity.
32. A system for determining an electrical property of a formation from tri-axial resistivity measurements acquired with a tri-axial logging tool, comprising a computer having a memory storing a program having instructions for:
- obtaining from the tri-axial resistivity measurements a first set of measurements representing couplings between a longitudinal transmitter and a longitudinal receiver;
 - obtaining from the tri-axial resistivity measurements a second set of measurements representing couplings between a transverse transmitter and a transverse receiver; and
 - deriving the electrical property of the formation from a difference measurement that is derived from the first set of measurements and the second set of measurements.
33. The system of claim 32, wherein the difference measurement is derived from $\alpha(\beta V_1 - V_2)$, wherein α and β are constants, V_1 is the first set of measurements, and V_2 is the second set of measurements.
34. A system for estimating an anisotropic resistivity ratio of an anisotropic formation from tri-axial resistivity measurements acquired with a tri-axial logging tool, comprising a computer having a memory storing a program having instructions for:
- obtaining from the tri-axial resistivity measurements a first set of measurements representing couplings between a longitudinal transmitter and a longitudinal receiver;

obtaining from the tri-axial resistivity measurements a second set of measurements representing couplings between a transverse transmitter and a transverse receiver; and

deriving the anisotropic resistivity ratio from a ratio of the first set of measurements and the second set of measurements.

35. The system of claim 34, wherein the ratio is $V_1/2V_2$, where V_1 is the first set of measurements and V_2 is the second set of measurements.

36. A system for determining a dip angle in a formation having dipping planes from tri-axial resistivity measurements acquired with a tri-axial logging tool, comprising a computer having a memory storing a program having instructions for:

obtaining from the tri-axial resistivity measurements a first set of measurements representing couplings between a longitudinal transmitter and a longitudinal receiver;

obtaining from the tri-axial resistivity measurements a second set of measurements representing couplings between a transverse transmitter and a transverse receiver; and

deriving an estimate of horizontal resistivity from a difference measurement derived from the first set of measurements and the second set of measurements; and

determining the dip angle from the tri-axial resistivity measurements and the estimate of horizontal resistivity.